Electronic Life-detection Instrument for Enceladus/Europa (ELIE)

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Abstract

Habitable regions of Europa may include a subsurface ocean and transient liquid environments within its icy shell. Ocean-surface communication may occur on 1–2 million-year (My) timescales or even more rapidly in chaos regions. Any ice-entombed organisms could remain viable at near-surface depths (10–100 cm) over 1–10 ky. The proposed Europa Lander will target samples at depths >10 cm, potentially enabling recovery of viable organisms if sampling conditions are ideal. Any life there would likely represent a separate genesis event from Earth life. Life detection approaches should therefore not only target life as we know it (contamination, common physicochemistry), but also as we don't know it, to lower the risk of false negatives. We propose to target prebiotic, ancient, or extant life using a novel fully-electronic single-molecule detection strategy. Now in early development (PICASSO), the Electronic Life-detection Instrument for Enceladus/Europa (ELIE) instrument will utilize quantum electron tunneling between nanogap electrodes to interrogate the electronic structure of single molecules. Nanogaps are formed by breaking a gold nanowire embedded on a silicon chip. Bending is then used to control the gap size in the sub-nanometer regime. A molecule can be identified by its characteristic conductance and interaction time as a function of gap size. This technology can detect and distinguish among amino acids, and detect RNA and DNA bases and short base sequences. The extrapolated limit of detection for single amino acids is ˜200 ppt after 5 min of sampling (˜1 pMol/g). Integrating upfront separation methods will enhance specificity and sensitivity. Our lab-bench prototype integrates a nanogap chip, low-noise amplifier, and a laptop for data processing. We target a ˜1 kg flight instrument mass. ELIE will be able to measure two key biosignatures: the amino acid complexity distribution, and charged informational polymers, through to be universal for aqueous based life.

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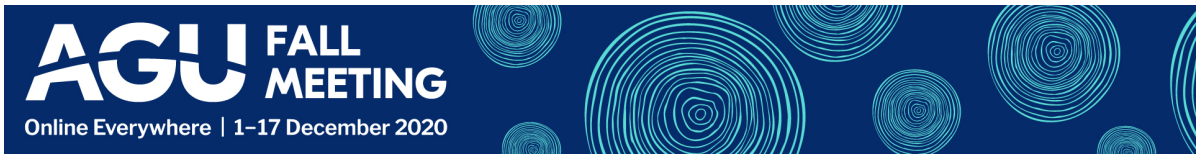

INTRODUCTION

Habitable regions of Europa may include a subsurface ocean as well as transient liquid environments within its icy shell. Recent work suggests potential ocean-surface communication on 1–2 million-year (My) timescales [1].

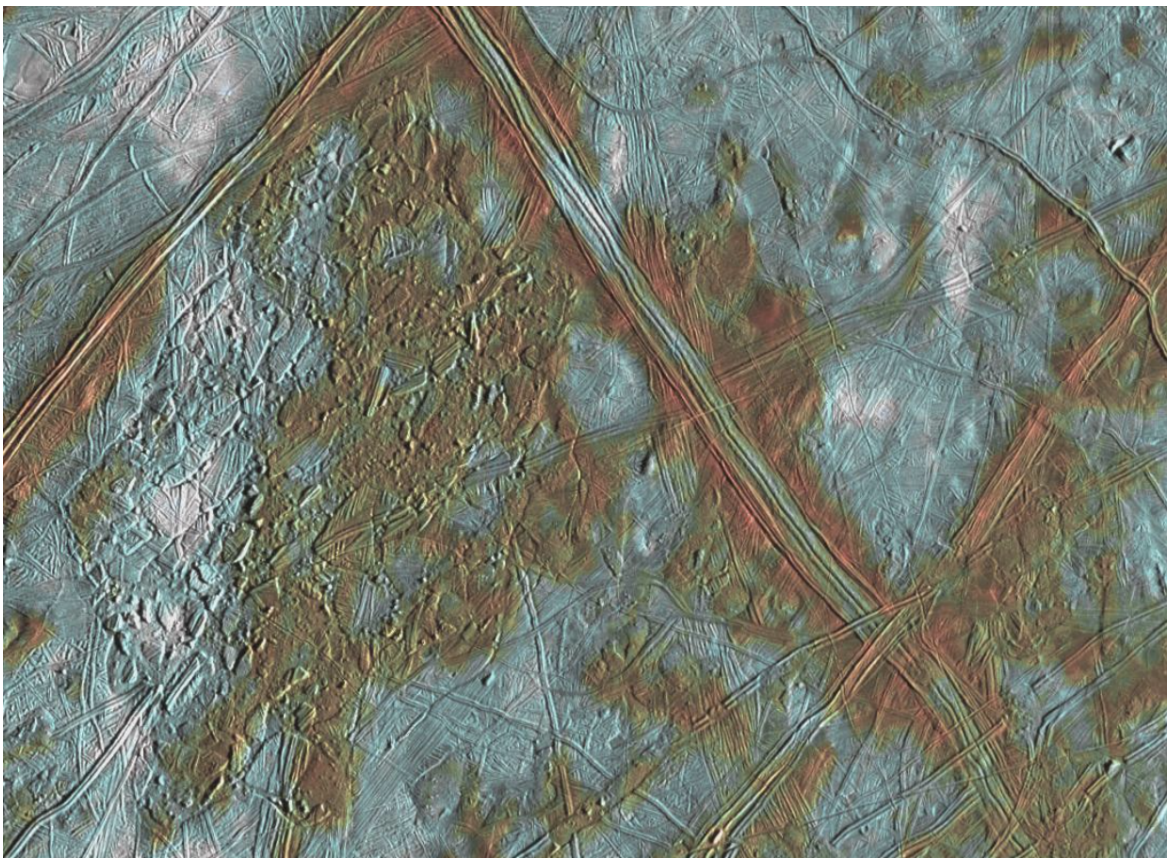

Fig. 1. Enhanced-color view of surface tectonic features of Europa, with Conamara Chaos region at left. Chaos regions may permit surface sampling of subsurface material with low exposure age. Image: NASA/JPL/Univ. Arizona, from PIA01296.

Even more rapid communication may occur in chaos regions (**Fig. 1**), which are thought to result from liquid exposure at the surface [2]. Current evidence is consistent with such events generating transient plumes [3], which could be observed by Europa Clipper, or past events inferred from remote sensing data.

BACKGROUND

On the basis of radiation-mediated bacterial killing models, organisms frozen into surface ice could remain viable at near-surface depths (10–100 cm) over 1–10 ky [4]. The Europa Lander will target samples at depths >10 cm [5], potentially enabling recovery of viable organisms if sampling conditions are ideal.

Any life on Europa would likely represent a separate genesis event from Earth life, based on low (<10-5) probabilities of meteoritic transfer of viable organisms from Earth and Mars [6].

Life detection approaches should therefore not only target **life as we know it** (to detect forward contamination or test universality of biochemistry associated with common physicochemical scenarios for origin(s) of life), but also **as we don't know it**, to lower the risk of false negatives. In the absence of extant life, detecting ancient life, or the extent to which prebiotic chemistry may be present, would remain invaluable.

ELIE INSTRUMENT CONCEPT

We propose to target prebiotic, ancient, or extant life at Europa using a novel **fully-electronic single-molecule detection** strategy.

Now in early development (PICASSO), the Electronic Life-detection Instrument for Enceladus/Europa (ELIE) instrument will utilize **quantum electron tunneling** between nanogap electrodes to interrogate the electronic structure of single molecules (**Fig. 2A**).

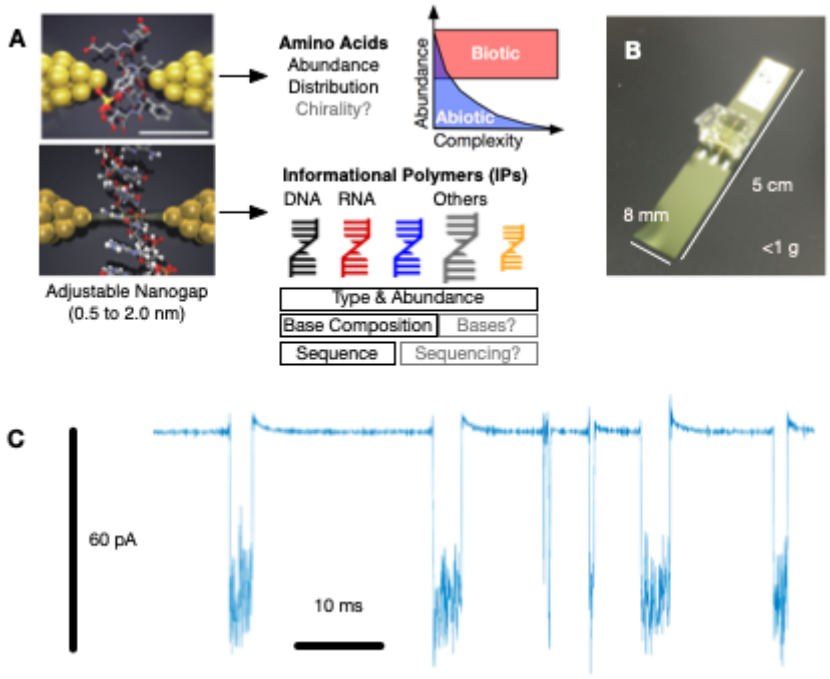

Fig. 2. Instrument overview. A) ELIE will utilize an adjustable nanogap to measure at least two key biosignatures: 1) Amino acid abundance distribution, and 2) Presence of informational polymers, not limited to DNA and RNA. B) Nanogap chip. C) Single amino acid events (proline, 10 μM; 100 mV applied bias).

Nanogaps are formed by breaking a gold nanowire embedded on a silicon chip (**Fig. 2B**). Bending is then used to control the gap size in the sub-nanometer regime (0.5-2.0 nm) to target a range of analyte sizes. A molecule can be identified by its characteristic conductance (or equivalently, current in picoamps at a given bias voltage, **Fig. 1C**) and interaction time as a function of gap size.

PROGRESS TO DATE

Prior work has demonstrated the ability to detect and distinguish among amino acids [7], and to detect RNA and DNA bases and short base sequences [8]. Chirally-specific detection may also be possible [9].

The extrapolated limit of detection (LOD) for single amino acids, without any preconcentration, is ~200 ppt after 5 min of sampling (~1 pMol/g). Integrating upfront separation methods will enhance specificity while further improving sensitivity.

Our lab-bench prototype integrates a nanogap chip, low-noise amplifier, and a laptop for data processing. Bandwidth requirements are around ~10^3 smaller than solid state nanopores. Even so, kHz to MHz sampling rates result in large data files that are reduced to events prior to classification.

Fig. 3. ELIE prototype during parabolic flight. Image credit: Steve Boxall/Zero Gravity Corp.

We have flown this initial prototype with manually-adjusted gap on a parabolic flight (**Fig. 3**) and are now constructing a system with automated gap adjustment. A data analysis pipeline has also been developed that performed automated event detection and enables subsequent machine-learning based classifier training and analysis.

CONCLUSIONS & FUTURE WORK

Nanogap technology has the potential to enable measurement of two proposed universal biosignatures: the amino acid abundance distribution, as well as, for aqueous-based life, long-charged polymers.

We target a ~1 kg flight instrument mass, including embedded data processing, suitable for Europa Lander or as part of other Ocean Worlds life detection missions.

Initial work supports the potential of this technology although the current technology readiness level (TRL) is low (2). With additional development, ELIE may facilitate seeking life **as we know it** or **as we don't know it**.

REFERENCES

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ABSTRACT

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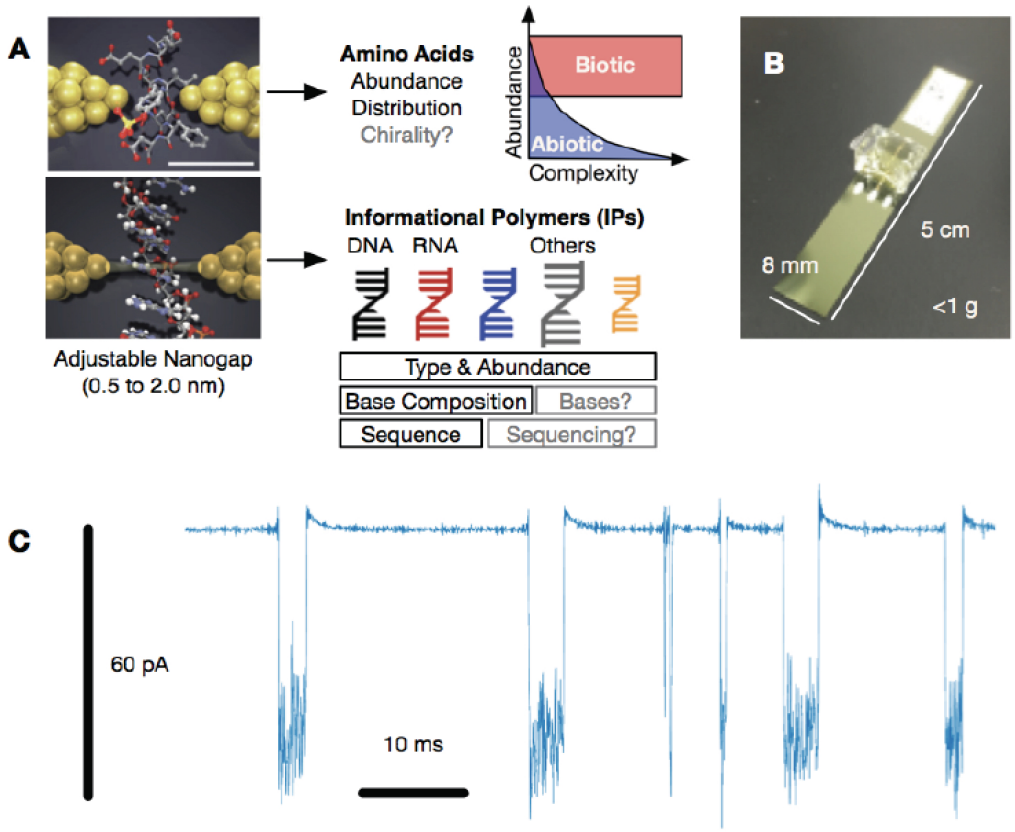

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